# CORRECTIVE MEASURES IMPLEMENTATION
# BEDROCK GROUNDWATER REMEDIATION

## • C-ZONE EVALUATION

**BUFFALO AVENUE PLANT**
**NIAGARA FALLS, NEW YORK**

**Prepared For:**
**Miller Springs Remediation Management, Inc.**

**Prepared By:**
**Services Environmental, Inc**
**Conestoga-Rovers & Associates**

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## EXECUTIVE SUMMARY

Miller Springs Remediation Management, Inc. (MSRM) is performing corrective actions on the bedrock groundwater flow regime at the Occidental Chemical Corporation (OxyChem) Buffalo Avenue Plant (Site) in Niagara Falls, New York. During a Site visit meeting on January 17, 2006, MSRM, OxyChem, and the New York State Department of Environmental Conservation (DEC) discussed issues associated with hydraulic containment in the C-Zone of the Lockport bedrock aquifer at the Site. Manual hand water level measurements in Site observation wells have routinely shown regional hydraulic containment based on mapping of the potentiometric surface but have not consistently demonstrated local hydraulic containment – as defined by inward gradients between select well pairs. MSRM agreed to re-visit the aspect of C-Zone containment drawing on the recent experience at the Hyde Park Landfill.

A plan to evaluate the C-Zone, entitled "Corrective Measures Implementation, Bedrock Groundwater Remediation, C-Zone Evaluation Work Plan" (Work Plan), was submitted to the DEC on March 17, 2006 and approved on March 28, 2006. The monitoring program proposed in that plan was initiated on May 1, 2006, and completed on August 28, 2006. Water levels in 23 C-Zone observation wells were monitored continuously during this time. These water level data, as well as historical hydrologic data, were reviewed to complete the report presented herein.

The key findings of the C-Zone Evaluation were:

1. Groundwater in the C-Zone is contained by the current extraction system pumping approximately 1,400 gallons per minute. This rate is more than required to achieve containment.
2. The potentiometric head in the C-Zone fluctuates by approximately 3 feet per day primarily in response to water level fluctuations in the NYPA conduits located near the western Site boundary.
3. Hydraulic containment was demonstrated using daily averaged water levels from the Site observation wells.
4. Hydraulic containment is not impacted by the operation and water level fluctuations in the NYPA conduits.
5. A conventional round of water level measurements from the Site observation wells cannot be used to interpret hydraulic containment, especially local hydraulic containment.

6. Water in the NYPA conduits flows into the C-Zone, it does not flow from the C-Zone into the conduits.
7. The existing C-Zone monitoring well network is generally representative of C-Zone conditions.

The 3-foot daily fluctuation in potentiometric head has been observed in previous studies. It is this large fluctuation and the rate at which the potentiometric head changes that confounds the interpretation of a conventional round of manual water level measurements. It is important to note that the C-Zone is a confined aquifer and is completely filled with water. The 3-foot daily fluctuation represents a change in pressure, not a large flow of water into and out of the aquifer. There is no "back-and-forth" flushing created by the change in pressure.

Based on the findings, the following recommendations are made:

1. An alternative method of monitoring containment should be developed and implemented. Monitoring pumping rates is one alternative for monitoring containment. Groundwater flow conditions do not change significantly during the year, therefore, maintaining the extraction system pumping at rates known to contain the Site-impacted groundwater is sufficient to ensure containment year-round. Other alternates are being evaluated.
2. Further assessment/study should be performed to determine what reduction in pumping rate could be implemented to maintain capture.
3. The lessons learned in the C-Zone may be applicable also to the B-Zone and D-Zone monitoring programs.

## 1.0 INTRODUCTION

Miller Springs Remediation Management, Inc. (MSRM) is performing corrective actions on the bedrock groundwater flow regime at the Occidental Chemical Corporation (OxyChem) Buffalo Avenue Plant (Site) in Niagara Falls, New York.

MSRM and OxyChem discussed issues associated with demonstrating containment in the C-Zone of the bedrock groundwater flow regime with the New York State Department of Environmental Conservation (DEC) during a Site meeting on January 17, 2006. At the meeting, MSRM agreed to re-visit the aspect of C-Zone containment drawing on the recent experience at the Hyde Park Landfill.

A plan to evaluate the C-Zone, entitled "Corrective Measures Implementation, Bedrock Groundwater Remediation, C-Zone Evaluation Work Plan" (Work Plan), was submitted to the DEC on March 17, 2006 and approved on March 28, 2006. The purpose of this Work Plan was to evaluate the existing C-Zone monitoring network to determine if hydraulic gradient monitoring is practical at the Site, or if an alternative method should be investigated to assist in demonstrating containment. It was noted in the Work Plan that the entire extent of the evaluation could not be defined until the tasks proposed therein were performed (i.e., the assessment of the C-Zone may be an iterative process). The first tasks to be performed were as follows:

Task 1 – Detailed Review of Monitoring Well Network; and
Task 2 – Shutdown and Startup Monitoring Program.

This report presents the results of the above two tasks.

## 2.0 BACKGROUND

### 2.1 CORRECTIVE ACTIONS AND OBJECTIVES

Corrective Action requirements for the Site are presented in the report entitled "Final Corrective Measures Study" (CRA, November 1998), and in Module II of the Plant's Part 373 Permit (revised February 10, 2002).

Corrective measures for the bedrock groundwater regime consists of a groundwater extraction system with pumping wells located along the western and northern Site boundaries. The bedrock groundwater extraction system consists of 19 extraction wells:

- six clusters of three extraction wells (intercepting the B-Zone, C-Zone, and D-Zone intervals of the bedrock; and
- one B-Zone well, BEW700B.

Figure 3.1 presents the locations of the Site extraction wells.

The extraction system was installed in 1995 and commenced operation in April 1996. The initial combined flow rate was approximately 800 gallons per minute (gpm). The system has been modified and augmented twice since that time and the current combined pumping rate is approximately 1,400 gpm.

The remedial action goals for the extraction system are as follows:

i) Restrict off-Site migration of OxyChem hazardous waste constituents in the bedrock groundwater. The definition of "restrict", as stated in Module II, is to eliminate significant off-Site discharge or migration of OxyChem hazardous waste constituents that pose a potential threat to human health or the environment to the maximum extent possible or technically feasible; and

ii) Reduce the concentration of hazardous waste constituents within the groundwater at the Site with time to acceptable State and Federal levels consistent with the use of the property and adjacent property.

The remedial criteria to achieve these goals are as follows:

On-Site:

i) Establish and maintain groundwater hydraulic barriers that contain the on-Site plumes of contamination. The hydraulic barriers shall control the movement of groundwater so as to restrict off-Site migration of hazardous waste constituents, and to ultimately restore the groundwater quality of the aquifers.

ii) Restore the quality of the on-Site bedrock groundwater aquifers to the levels at or below the Groundwater Performance Standards set forth in Module II.

Off-Site:

i) Establish and maintain a groundwater capture zone that extends from the property boundary outward into the off-Site plumes. The intent of the groundwater capture zone shall be to control the movement of off-Site groundwater so as to reduce any further degradation of the off-Site aquifers, and to restore the groundwater quality of the aquifers.

ii) Restore the quality of the off-Site bedrock groundwater aquifers to the levels at or below the Groundwater Performance Standards set forth in Module II.

iii) Reduce the concentrations of hazardous waste constituents (Site-Specific Indicators (SSIs)) in the off-Site contaminant plumes by 50% within 10 years after start up of the extraction system; by 75% within 15 years after system startup compared to Off-Site Investigation (OSI) sampling results (or SSI sampling results if no OSI results exist).

## 2.2 PERFORMANCE REQUIREMENTS

Module II of the Permit states: "*hydraulic containment will be evaluated by use of potentiometric surface maps derived from "point in time" data. The hydraulic monitoring program must be capable of distinguishing changes in the potentiometric surface which have resulted from implementation of the Corrective Measures from background changes unrelated to the Corrective Measures (such as changes induced by fluctuations in the Niagara River level or surcharging of the NYPA Forebay Canal). Monitoring may involve both instantaneous and continuous water level monitoring.*"

While MSRM and OxyChem believe that operation of the extraction system has achieved the remedial action goals, complex hydraulic conditions have confounded efforts to demonstrate hydraulic performance as outlined in Module II of the Permit. In particular, operation of the bedrock groundwater remediation system has resulted in regional hydraulic containment in the C-Zone interval based on potentiometric surface mapping, but it has not resulted in the continuous demonstration of hydraulic containment via inward hydraulic gradients at the Site boundary.

The difficulty associated with demonstrating containment is in large part due to large diurnal fluctuations in potentiometric head related to water level changes in the Niagara River (River) and the New York Power Authority (NYPA) conduits used to transfer water from the upper River to the Robert Moses power generating station approximately five miles north of the Site. The NYPA conduits are in direct communication with the D-Zone and the C-Zone of the bedrock. Figure 2.1 presents a generalized section showing the conduits and the approximate depth of the B-, C-, and D-Zone bedrock intervals. Water levels fluctuate by approximately three feet per day in the conduits and water level fluctuations can be very rapid. The potentiometric head in the bedrock responds quickly to the changes in the conduits. In addition to the influence of the conduits and the river, the bedrock flow regime is heterogeneous, is highly transmissive beneath much of the Site, is confined, there are vertical hydraulic gradients, and the bedrock is fractured. In summary, the heterogeneous bedrock system combined with anthropogenic influences, make groundwater flow interpretation based on a conventional round of water level measurements nearly impossible.

## 2.3 PREVIOUS RELEVANT INVESTIGATIONS

### 2.3.1 SDCP CONTINUOUS MONITORING ~ 1990

In 1989 and 1990, continuous monitoring efforts were completed in select A-Zone, B-Zone, C-Zone, and D-Zone monitoring wells as part of the Supplemental Data Collection Program (SDCP). The purpose of the continuous monitoring was to determine the hydraulic head variation in the bedrock resulting from daily River stage fluctuations and other possible influences. Table 2.1 lists the wells that were monitored with electronic water level recorders and the duration of the monitoring.

The monitoring data collected showed a daily fluctuation in potentiometric head as large as 3 feet. The observation wells also responded to fluctuations in the NYPA conduits and/or the River. However, a correlation between water level fluctuations in observation wells and distance from the conduits or river was not apparent. A reduction in fluctuation amplitude and an increasing "lag time" are often observed[1] in

[1] Ferris, J.G. 1952. Cyclic fluctuations in water level as a basis for determining aquifer transmissibility. U.S.G.S Open File Report

aquifers influenced by a hydraulic boundary with cyclic water level fluctuations (e.g., the NYPA conduits).

### 2.3.2 C-ZONE WELL PAIR CONTINUOUS MONITORING~ 2004

Due to difficulties demonstrating hydraulic containment using potentiometric surface maps, hydraulic gradient monitoring was attempted as an alternative. Electronic water level recorders were installed in select well pairs to collect continuous monitoring data and observe groundwater fluctuations and hydraulic gradients.

Several continuous monitoring events have been conducted to examine "local containment" at the Site boundary, the most recent being conducted in May/June 2004 (CRA, 2006). This event was undertaken to examine "local containment" under higher pumping rates at bedrock extraction wells BEW703C and BEW705C. The continuous monitoring tests performed with a larger capacity pump in these wells showed the following:

i) The higher capacity pump produced average inward gradients between at least the outer well pairs along each monitoring well transect;

ii) The hydraulic influence of the extraction system operation was observed at all three monitoring wells located approximately 300 feet north of the Site boundary;

iii) Instantaneous measurements of gradients are likely not indicative of actual containment due to fluctuating groundwater elevations. Even when average inward gradients are achieved, instantaneous outward gradients may be observed a percentage of the time;

iv) According to the monitoring well network, pumping the extraction system caused the hydraulic gradients to increase away from the extraction system at some well pairs, exactly the opposite of what is expected.

The anomalies observed in items iii) and iv) above are attributed to the fact that bedrock groundwater elevations are highly variable at the Site due to the permeable fractured bedrock, vertical hydraulic gradients, and rapid changes in water levels in both the River and the NYPA power project forebay and conduits.

Conceptually, if the extraction system is containing groundwater flow, the wells further from the extraction wells will have a water level higher than the wells close to the extraction wells (i.e., an "inward flow direction"). This conceptualization is valid for a homogeneous porous medium with all of the observation wells located appropriately and completed in exactly the same hydraulic unit. The data collected during the May/June 2004 continuous monitoring study raise some questions as to the validity of these assumptions at the Site.

## 3.0 C-ZONE HYDROLOGIC EVALUATION RESULTS

As presented in the Work Plan, the first tasks to be performed for the C-Zone Evaluation were as follows:

Task 1 – Detailed Review of Monitoring Well Network; and
Task 2 – Shutdown and Startup Monitoring Program.

Task 1 was the review/evaluation of all C-Zone monitoring wells. The purpose of the task was to determine which monitoring wells are "representative" of the C-Zone conditions and could be used in the long-term monitoring program. A preliminary review of historical manual and continuous water level data from the C-Zone demonstrated that identifying "representative" and "non-representative" C-Zone wells (i.e., wells with water levels that do or do not reflect the potentiometric head in the C-Zone interval), was essentially impossible with the existing database. The daily fluctuations in the C-Zone potentiometric head created by the NYPA conduits confounded reliable assessment of manual water level measurements. The historical continuous data did not study a single hydraulic zone (only portions along the north Site boundary), which did not allow a comprehensive comparison of wells within the same zone to be performed. Therefore, the detailed monitoring defined for Task 2 was necessary to assess the C-Zone monitoring wells. As a result, Tasks 1 and 2 are discussed together in the following discussion of findings.

Based on this, no changes to the shutdown and startup monitoring program proposed in the Work Plan were necessary. It should be noted that short shutdown tests were performed on BEW700B and BEW701B, C, and D in addition those proposed in the Work Plan.

### 3.1 PURPOSE OF THE SHUTDOWN AND STARTUP MONITORING PROGRAM

The purpose of the shutdown and startup monitoring program was to determine if hydraulic gradient monitoring is practical at the Site, of if an alternative method should be investigated for demonstrating containment. The monitoring completed for the shutdown and startup monitoring program provided a set of "continuous" groundwater elevations from 23 observation wells in the C-Zone. Water levels were recorded at 5-minute intervals from May 2006 through August 2006. Previous continuous monitoring efforts described in Section 2 identified the influence of the NYPA conduits and River on potentiometric head. However, none attempted to fully monitor a single bedrock hydraulic zone.

Potentiometric surface mapping has been the principle method for evaluating groundwater flow and hydraulic containment in the bedrock. To date, the potentiometric surface mapping has been based on conventional rounds of manual water level measurements in the observation wells. While the manual field measurement procedures have been defined to minimize the influence of cyclic fluctuations in potentiometric head created by operation of the NYPA conduits and the River, the fluctuations continue to hinder the analysis of groundwater flow.

The continuous monitoring data collected during the shutdown and startup monitoring program were used to develop potentiometric surface maps for the C-Zone. The influence of cyclic water level fluctuations in the NYPA conduits and the River were eliminated by daily averaging of the continuous water level data. The new potentiometric surface maps demonstrate that the groundwater extraction system is effectively containing Site groundwater in the C-Zone. Hydrographs and potentiometric surface maps are presented here to demonstrate that daily averaging to eliminate cyclic fluctuations in potentiometric head is an acceptable methodology.

## 3.2 WATER LEVEL MONITORING

Twenty-three C-Zone observation wells were instrumented with electronic water level recorders (Solinst Levelogger) for the shutdown and startup monitoring program in accordance with the Work Plan. The wells were monitored between April 24 and August 28, 2006. The entire data set is included on a compact disk included with this report. The table below lists the wells that were instrumented. Water levels were recorded at 5-minute intervals. Manual depth to water measurements were taken seven times during the monitoring period to calibrate and validate the water level recorders. Table 3.1 presents the manual water level data. The following table lists the wells that were instrumented with water level recorders, include locations where the recorders were relocated as described below.

| Well | Installed | Removed |
|---|---|---|
| OW139 | 4/24/2006 | |
| OW401C | 4/24/2006 | |
| OW403C | 4/24/2006 | |
| OW404C | 4/24/2006 | |
| OW407C | 4/24/2006 | |
| OW408C | 4/24/2006 | |
| OW409C | 4/24/2006 | |
| OW410C | 4/24/2006 | 5/10/2006 |
| OW411C | 4/24/2006 | |
| OW412C | 5/10/2006 | |
| OW415C | 4/24/2006 | 5/10/2006 |
| OW415B | 5/10/2006 | |
| OW416C | 4/24/2006 | |
| OW417C | 4/24/2006 | |
| OW418C | 4/24/2006 | |
| OW419C | 4/24/2006 | |
| OW420C | 4/24/2006 | |
| OW638 | 5/10/2006 | |
| OW649C | 4/24/2006 | |
| OW651C | 4/24/2006 | |
| OW652C | 4/24/2006 | |
| OW653C | 4/24/2006 | 5/10/2006 |
| OW654C | 4/24/2006 | |
| OW658C | 4/24/2006 | |
| OW659C | 4/24/2006 | |
| OW668C | 4/24/2006 | |
| Niagara River | 4/24/2006 | |
| Barologger | 4/24/2006 | |

Figure 3.1 presents the locations of the C-Zone extraction and observation wells.

The water level recorders in wells OW410C and OW653C wells were relocated to wells OW412C and OW638 on May 10, 2006. In general, the water levels in C-Zone wells responded to the fluctuation of the NYPA Forebay. However, wells OW410C and OW653C showed essentially no water level fluctuation. This shows that both wells are completed in low transmissivity areas of the bedrock and water levels in the wells cannot respond quickly to the changes in the aquifer water levels. Thus, monitoring of these wells would not provide representative data and the water level recorders were relocated.

The water level recorder in OW415C was relocated to well OW415B on May 10, 2006. This decision was based on inspection of the well open intervals. Figure 3.2 presents the open intervals for the Site extraction wells and the C-Zone observation wells. OW415C appears to be completed in the bottom of the D-Zone rather than in the C-Zone;

OW415B is close to the center of the C-Zone. Thus, OW415B was considered more representative for the current study.

In addition to the recorders in 23 observation wells, a barometric pressure recorder (Solinst Barologger) and a river level monitoring recorder (Solinst Levelogger) were installed.

On May 14, 2006, the groundwater extractions wells were shutdown. The extraction system was restarted on June 9, 2006. For several days prior to the restart, extraction wells were being tested and the influence of these tests can be observed in many wells. On restart, not all of the extraction wells were fully operational. Figure 3.3 presents a graphical summary of the B-, C-, and D-Zone pumping rates during the week prior to the extraction system shutdown. Table 3.2 presents the weekly average pumping rates for the second quarter of 2006.

Short shutdown tests were completed on each of the recovery wells at locations BEW702, BEW703, BEW704, BEW705, and BEW706 between June 26 and July 1, 2006. These shutdown tests proceeded as follows:

- Each extraction well cluster was tested on one day.
- With all 19 extraction wells pumping:
    - The D-Zone extraction well at a location was shut down.
    - Two hours later the C-Zone well at the same location was shut down.
    - Two hours later the B-Zone well was shut down.
    - Two hours later all three wells were turned back on.

The two-hour shutdown period was considered sufficient time to see near total recovery. The aquifer responds very quickly to a shut down due to both the high aquifer transmissivity and low storage coefficient.

Extraction wells BEW701D, BEW701C, and BEW701B were shut down as described above on August 24, 2006. Extraction well BEW700B was shutdown on August 23, 2006 for six hours.

### 3.3 HYDROGRAPHS

Figure 3.4 present hydrographs for each of the observation wells and the River. These figures present two months of data, May and June 2006, including the two-week system shutdown and the testing of individual wells completed between June 26 and July 1, 2006.

The wells in the C-Zone are fluctuating in response to the water level fluctuations in the conduits. Due to its close proximity to the conduits and its location beyond the influence of pumping, the water level in OW139 is considered a surrogate for the conduits. As shown in Figure 2.1, the excavation for the NYPA conduits was deep enough to intercept the top of the C-Zone. However, the C-Zone is not intercepted by the River. This geometry is consistent with the observations made during the current study (i.e., that the NYPA conduits control the potentiometric head fluctuations in the C-Zone and the River influence is insignificant).

Well OW139 was defined as a point of reference, or datum, for Site water level measurements. Water level fluctuations in this well should follow closely the water levels in the NYPA conduits and it also is far enough away from the extraction system that it is not influenced by pumping. There are two limitations in using OW139 as a surrogate for the conduits that must be noted:

- OW139 intercepts only part of the C-Zone and all of the shallower D-Zone. Because it intercepts two intervals, the water level in OW139 is a composite of the C-Zone and D-Zone water levels. There is an upward gradient at OW139 due to the Falls Street Tunnel (FST) draining the shallow bedrock. Due to the well construction and location near the FST, the water level elevation in OW139 is lower than if it were completed only in the C-Zone.
- OW139 is 12 inches in diameter. Due to the large diameter, well bore storage and the water levels in OW139 are slightly damped, resulting in a smaller amplitude of fluctuation than the conduits and a slight time lag. This can be demonstrated by comparison with C-Zone wells close to the conduits on Site. An on-Site C-Zone well was not selected as a surrogate for the conduits because all of the on-Site wells responded to pumping.

Figure 3.5 presents a comparison of the water levels in well OW401C and OW139. Two days of data are presented to allow a visual comparison between these two wells. These two days are non-pumping conditions; however, inspecting any two days of data would result in a similar observation – these wells rise and fall together. Well OW401C is, on the average, 2.41 feet higher than OW139 on these two days. The standard deviation of the difference between OW401C and OW139 is 0.11 feet. The majority of the monitoring wells respond similarly to OW401C, rising and falling in unison with OW139. With respect to groundwater flow, the C-Zone potentiometric surface is rising and falling over the course of a day and the shape of the potentiometric surface and groundwater flow patterns should be relatively stable.

It is also important to recognize that the rise and fall of water levels in a well reflect a change in pressure in the aquifer (potentiometric head), not a recharge and release of 3 feet of water each day. The C-Zone is a confined aquifer system with extremely low storage, the aquifer is filled with water and the pressure in the aquifer changes by 3 feet daily. There is no change in the water level as the aquifer is completely filled.

Not all wells follow OW139 as consistently as OW401C. In particular: OW409C, OW411C, OW412C, and OW638, exhibit a reduced amplitude of fluctuation and a lag time between when a peak occurs in OW139 and one of these wells. As noted previously, wells OW410C and OW653 also exhibited very little change in water levels. These wells are located the farthest distance from OW139.

Figure 3.6 presents two days of data for OW412C and OW139. Compared to OW139, OW412C has a reduced amplitude of fluctuation and lag time ("damping" effects). Damping is attributed to well bore storage, aquifer properties, and distance from the conduits. Well bore storage effects occur in all wells when potentiometric head in the aquifer is changing. Changing water levels in a well means that water is flowing into or out of the well; therefore, the potentiometric head in the aquifer must be higher or lower than the level in the well. The more transmissive the aquifer and the smaller the well bore, the more quickly the well responds. In summary, the water levels in OW412C and the other wells that lag OW139 are not accurate reflections of the aquifer water levels.

## 3.4 NON-PUMPING C-ZONE POTENTIOMETRIC SURFACE

As described above and demonstrated in the hydrographs, while water levels in the observations wells fluctuated approximately 3 feet over the course of a day, the water levels were generally rising and falling in unison. As a result, the potentiometric surface rises and falls over the course of a day but the shape of the potentiometric surface and groundwater flow patterns should not change significantly. If water levels are rising and falling in unison, interpretation of the water level data from observation wells may be developed using data from a single instant in time, or using a daily average water level (a daily averaging was selected as the cyclic water level fluctuations are daily